TIBIO-FEMORAL CONTACT STRESS AND FORCE WITH KNEE ALIGNMENT VARIATION

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Pathological alignment of the knee can occur with traumatic injury to the knee joint or from degradation of the articulator. Cartilage wear often occurs more in the medial compartment of the knee which causes a valgus deformity of the knee. Varus deformities cause the knee to be positioned more lateral for a given foot position. This knee mal alignment can actually increase the contact load on the medial side of the knee causing a positive feedback situation, which can increase the cartilage or bone wear on the medial side. A similar situation can of course exist with a lateral decrease in joint height leading to varus knee position medial to the normal position. Surgical correction of the type of pathology can consist of osteotomies of the tibial or femur medially or laterally. The osteotomy would be an opening or closing wedge type depending of the deformity type and side of the bone being moved.

The purpose of the current study is to establish an experimental model of knee mal-alignment and surgical correction. This experimental data will be used to validate a mathematical model of the knee compartment force. The experimental and mathematical model results will later be used to optimize treatment of knee articulating surface degradation and mal-alignment.

METHODS:

The pressure measurement system used was "Ultra Super Low" Fuji Presale Film®. This is a two-part pressure sensitive film: one part developer and one part color indicator. The indicator side displays increasingly dark shades of red with increasing pressure beyond a threshold. The film shows a near linear relationship between pressure and density over a fairly narrow range. The film becomes saturated at pressures near 1 MPa and does not register pressure below 0.1 MPa in our calibration experiments. Pressure versus density was obtained using the supplied calibration chart. This calibration was experimentally verified using a rubber disk to apply pressures of varying magnitudes. The experimental calibration was found to correspond satisfactorily to the supplied calibration chart.

Axial loads were applied to the knee using a computer controlled lead screw type machine with a capacity of 4400 N.

The six fresh frozen cadaver knees from donors age 69-76 years were obtained. The tibia and femur were cut to a length of 6-8 inches from the joint line. The bones were then potted in cylinders with a low melting point alloy. Threaded metal rods 1/2 inch in diameter were attached to the pots. The threaded rods were then attached to the loading frame through two universal joints. The lower, tibia universal joint was mounted in line with the tibial axis while the femoral universal joint was offset in order to simulate the geometry of the femoral neck and hip joint. The total femoral length was set to 18 in. to simulate a typical anatomical geometry. The angle between the femoral axis and load axis was initially set at 6 degrees.

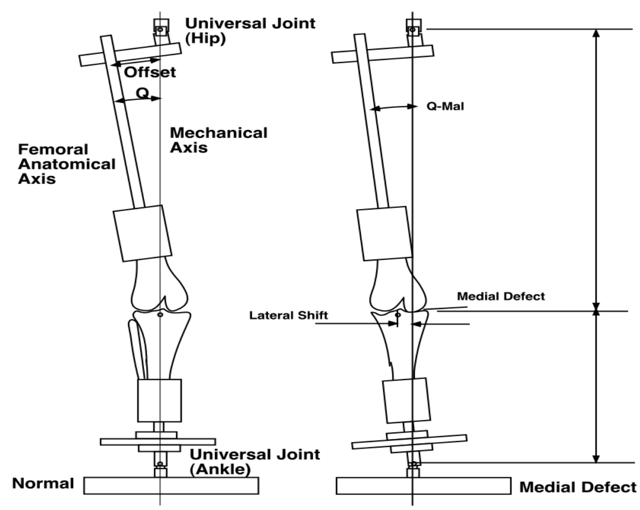

Figure 1: Knee loading set up for contact pressure measurement.

The specimen was aligned such that the canter of load passed in a straight line from the center of the hip joint universal joint through the center of the knee to the ankle universal joint.

Film packs were created by cutting the film to a shape matching the contact area for the medial and lateral compartments of the knee. These were then placed in clear tape to make a waterproof package. The tape was trimmed to within 2 mm of the edge of the tape with a tab of tape left on the anterior border for use as a handle.

A distraction load of 88 N was applied to the joint in order to create a space for the film packs. The film was placed in the medial and lateral compartments of the knee joint. Pins in the bone along with holes in the film were used to locate the film. A axial load of 176N was then applied for a 5 sec. After loading the intact joint, an osteotomy was performed to simulate a medial defect of the knee. A varus angle of six degrees was created relative to normal. The pressure was then retested in this configuration. A six degree valgus deformity was created next and the knee retested. In three knees the medial meniscus was removed after the intact testing and after varus defect in three knees.
Film was scanned along with the calibration chart. The scans were analyzed with an image analysis program, and the pressure, contact area, and load were calculated for each side of the knee.

RESULTS:

Contact Area

In order to accommodate the variation in the congruency of the contact area, the % area on medial side was calculated. The percent of the contact area on the medial side area varied with knee alignment (p.<05) and presence of a medial meniscus (p<.02) (Figure 2.).

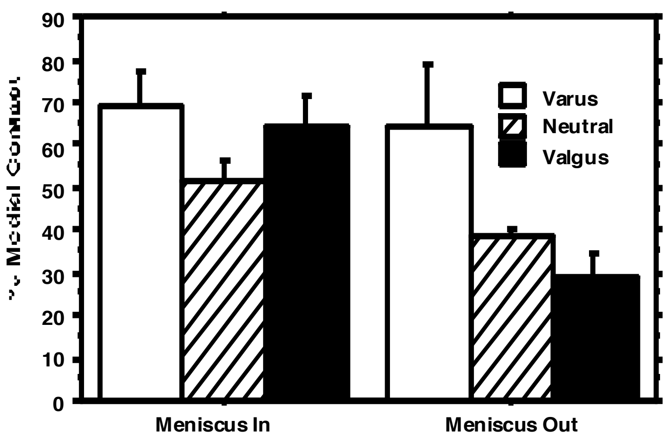

Figure 2. Percent contact area on medial side versus knee alignment and meniscus.

The measured contact area defined as the area with sufficient load to produce a pattern on the film was divided into central and peripheral portions. The peripheral area was significantly higher with the presence of a meniscus (180 mm^2 versus 117 mm^2, p <0.01).

Pressure

Valgus alignment significantly decreased peak stress in the medial contact area compared to varus and neutral alignment (Figure 3). The presence of a medial meniscus decreased average peak pressure to 0.76 MPa from 0.84 MPa but this decrease was not statistically significant.

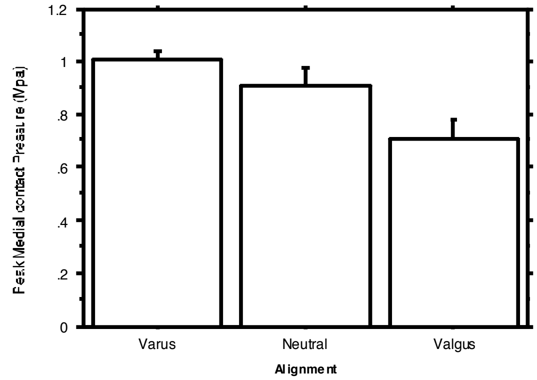

Figure 3: Peak medial contact stress versus alignment.

Load

In general the calculated load from the measured contact was less than the applied load. The total contact load calculated for the contact areas was not affected by the presence of an intact meniscus for these specimens. The knee alignment however had a significant effect on the load distribution between the medial and lateral condyles. The more lateral the knee position was (varus alignment), the more the load was shifted towards the medial condyle (Figure 4).

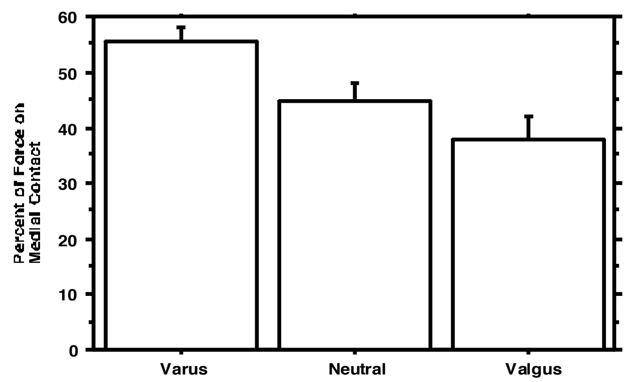

Figure 4: Percent of forces on medial contact area.

DISCUSSION:

Contact pressure measurements using the Fuji film was reproducible and seemed to give reasonable results. The lower load calculated compared to applied is probably due to peak stresses which saturate the film or force bypass to some other structure. The meniscus at the medial area tended to increase the contact area, which is to be expected due to its function. This is confirmed also by the increase in peripheral contact area with the meniscus present. The effect of meniscus removal was not as great as anticipated on average pressure and this may be due to the age of the specimens which could have had less structurally viable menisci than younger donors. The increase in medial contact stress due to lateral shift of the knee is also a reasonable result since the line of force shifts medially with respect to the knee in this case. The increase in force therefore results. With this experimental model established, future work will involve implementing a mathematical model of this mechanical system. Once this model has been validated by these experimental results surgical correction of knee defects will be studied both mathematically and experimentally and optimized.